pological Section of the British Association for the Advancement of Science.

Heat Centers in Man. ISAAC OTT, M. D. Brain, January, 1889.

From the study of the lower animals the author recognizes six centers, injury to which causes increased temperature. These are described as the cruciate, about the Rolandic fissure, the Sylvian at the junction of the supra and post-Sylvian fissures, the caudate nucleus, the tissues about the corpus striatum and the optic thalamus near the median line, and the anterior end of the optic thalamus itself. A few cases are presented which are considered to indicate the existence of similar heat centers in man, and in the closing sentence the task of localization with the required precision is said to devolve upon neuropathologists.

II.—EXPERIMENTAL.

COLORED SHADOWS.[1]

Whenever an object is illuminated from two different directions by lights which are approximately equal in intensity but more or less different in color, the shadows thrown by the object, especially if they fall on a white ground, will be colored. The difference in shade may be so slight that we ordinarily regard both lights as white, as in case of candle and moonlight, yet the colored shadows will appear. When the light from one source is white, its shadow is of the color of the other light; for it is illuminated by the latter light alone. But the other shadow, although it is illuminated only by white light, yet always appears of a color complementary to that of the neighboring field, which is illuminated by both lights together.

These shadows may be obtained in various ways, and they are of by no means infrequent occurrence. We see them in the theatre when colored lights are used, or in our room if we have a colored shade for our lamp. We notice them sometimes on the page we are reading, when the window shade is partly drawn, so that the daylight enters partly uncolored through the window, and partly slightly tinted through the shade. Goethe and others speak of beautiful effects caused by the setting sun shining on snow-covered fields. For experimental purposes the best plan is to use a dark room arranged in a manner soon to be described.

The color of the complementary shadow is at first sight hard to account for, and has given rise to much discussion. Helmholtz and others think that it is an effect of contrast with the neighboring field, due to a "deception of judgment," and that colored shadows form an *experimentum crucis*[2] of the psychological nature of color-contrast. There are certain facts connected with the shadows, they maintain, which entirely overthrow the physiological theories. We hope to show that in this they are wrong; that all the phenomena presented by these shadows can be explained at least equally as well —many of them, it seems, very much better—by a purely physiological theory.

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[1] Written for the Graduate Course in Psychology at Harvard University.

[2] Von Kries, "Gesichtsempfindungen," p. 131f

In the first place, the color of the shadow is evidently in some way due to the presence of the colored light which surrounds it; for it is always complementary to the latter, and if no colored light is present, the shadow appears grey. Yet in every case it is illuminated by white light only, and hence objectively does not change in color.

Its color then must be due either to retinal fatigue or to contrast of color. Helmholtz claims that it is primarily and especially the latter; for the color is seen at once if one takes care to regard the shadow without having previously looked at the surrounding field, or allowed the colored light to affect the retina. Its color is intensified, however, by aid of fatigue, if the eye is allowed to wander about between the shadow and the colored field. The facts which he and others rely upon to prove conclusively that this contrast is due to psychological, and not to physical or physiological causes, are described by him as follows. His shadows are produced by using candle-light, which is reddish yellow in color, and weakened day-light. They are therefore colored blue.

"Take a tube, blackened inside, and place it so that when one looks through it the eye sees only parts of the paper which lie in the shadow of the candle-light. Let at first only day-light fall upon the field, then look through the tube, and then allow the candle-light to enter. One sees now nothing of the parts illuminated by the candle-light, does not notice its presence, and the appearance of the portion of the paper which he sees through the tube remains unchanged. It follows that objectively the color of the paper in the shadow of the candle-light is unchanged.

"If however the observer directs the black tube through which he is looking so that a portion of the field which is being observed is lighted by the reddish-yellow light of the candle, then the shadow of the candle-light becomes blue. When the blue has very intensely developed itself, turn the tube again so that nothing but the subjective blue is in the field of view. Now the blue remains whether we allow the candle-light access to the rest of the paper or cut it off entirely,—which of the two we do is indifferent to the observer, since under these circumstances he sees nothing of the part of the field which is illuminated by the candle, and he cannot know whether its light is present or not. The blue color in such a case is so persistent that Osann decided it was objective. This assumption is easily disproved, in that the blue color still remains when the candle-light is extinguished. In the moment however when one removes the black tube from the eye, the subjective blue disappears, since one recognizes it as identical with the white which fills the rest of the field of view. No observation shows more strikingly and plainly the influence of the judgment on our color sensations. After the judgment is once fixed in consequence of the contrast, whether it be successive or simultaneous, that the color in the shadow of the candle-light is blue, the color still remains apparently blue even when the circumstances which have led to this decision are removed; until by removing the tube we make possible a new comparison with other colors, and through new facts allow our judgment to be otherwise determined." [1]

The nature of this "deception of judgment," which leads us wrongly to think the shadow colored, is concisely described by

[1] Helmholtz, "Physiologische Optik," p. 394f.

Delbœuf in speaking of these experiments. The experiment proves, he thinks, "that the sensation of color can depend upon an act of thought alone."[1] If we look through a pane of red glass, rays which come through it to the eye from a white object will be red. Rays coming from a green object, if the conditions were perfect, would be entirely cut off, and the object would appear black; but the red glass always lets through more or less white light, and with every green is mixed some white; so that some grey rays would come to the eye from a green object. Nevertheless we do not judge the white object to be red, nor the green to be grey, but they appear to us more or less in their natural colors. This is because we are accustomed to judge of the colors of objects through varying modifications of the light which surrounds us, and which changes continually according to the state of the atmosphere, the aspect and disposition of the clouds, the color of reflecting objects, etc. Hence we have learned to judge correctly the color of objects in making allowance for the color of the medium through which we look. So in the case of the colored shadow, which in reality is grey, we judge it to be blue—if we are using Helmholtz' method for producing them—because we think that we see it through a reddish-yellow medium. "When we have once judged it blue, if we make use of our tube, there is no reason for us to change our decision; nor is there any more reason to change it if the colored light is removed, since we observe no change of condition. But when colored light and tube are both removed, we judge at once that the shadow is grey, because we believe that we see it through a white medium; and when we replace our tube before the eye we continue to judge it grey, whatever change is made in the color of the light, because again we observe no variation of condition such as would cause us to modify our judgment. It is then proved, we believe, that the judgment of color rests not only upon a special property of the visual sensorial substance, but also upon unconscious anterior judgments, which have become so through habit, or because they depend upon instinct."[2]

Now let us examine these experiments more closely, and see if we cannot explain the facts quite as well by a purely physiological theory. For these experiments the following arrangements yield the most satisfactory results. In the shutter of a dark room is an opening, which, being furnished with a pane of colored glass, allows only colored light to enter. At this opening is fixed a small shutter, so arranged that it can be closed by means of a cord reaching to the table on which the shadows are cast, and can open itself automatically when the cord is released. White light is obtained through an opening some distance removed from the first, or from a gas jet or lamp. An opaque object on the table throws two broad shadows on to a white ground. Suppose now that we place a pane of green glass at the opening. The shadow cast by the white light will be strongly illuminated by the green light, and will be of that color. The general ground, illuminated by both lights equally, will be of a whitish green. The second shadow will appear to be of a color complimentary to this, a strong red, although it is illuminated only by white light. It is with this latter shadow alone that we are concerned.

[1] Delbœuf, "La Psychologie comme Science naturelle," p. 58.
[2] Ibid, p. 61ff.

First let us see if, as Helmholtz says, we have to do with contrast effects only, and not with retinal fatigue. For this purpose we arrange our apparatus with the green glass at the opening, and have upon the table a tube so fixed to an iron standard that its upper end is stationary, while its lower end can be moved about at will. Let the shadow fall upon the paper, and mark a point within it at a little distance from its margin. Then arrange the tube in such a way that by looking through it you can see a portion of the shadow, including the point marked and also a portion of the colored field adjoining. Now by means of the cord close the small shutter, thus excluding the green light, rest the eye thoroughly, and then apply it to the tube. Carefully fixate the point marked, keeping the eye entirely from wandering, and open the shutter. A portion of the field visible will at once appear green, from the green light falling upon it. The shadow will appear of a slightly red tinge, with a tendency to decrease in intensity. This red is evidently purely an effect of contrast with the green, if the eye has been kept rigidly fixed. If the tube is now so moved as to cover the shadow only, and a new point is at once fixated, the red does not last for an instant on that portion of the retina on which the image of the shadow had fallen, but rather gives place to green or grey; while the other half of the retina, on which green light alone has worked, does experience the sensation of red, for it has been exposed to green-fatigue. This result follows clearly only under the most favorable circumstances. The difficulty of steady fixation, and of renewing the fixation after moving the tube, make the experiment difficult of success. The result varies somewhat also according to the length of time of fixation, to the size of the tube, to the amount of diffused light reflected from its sides, to the strength of the colored light and vividness of the shadow, to the care with which the eye is kept wide open, etc. Of course the various phenomena which accompany steady fixation, —the periodical disappearance and reappearance of the field, etc,— do not enter into consideration. But one result is always certain, if the experiment be performed with care,—the red of the shadow does not persist. The following modification of this experiment is perhaps less liable to failure on account of the difficulties mentioned above. After fixating the marked point in the red shadow close the shutter, thus excluding the green light, without moving the tube. Now the green almost surely gives place to red, and the red to a faint green.

This experiment gives us a very important result: the red color of the shadow, which Helmholtz found so lasting even when the green light was shut off, is not purely a contrast red; for the pure contrast red, as we have just seen, always disappears at once when the contrasting field is removed. The red which persists when the green light is removed is only the red induced when the eye has been allowed to wander over the field, or when it has been already somewhat exposed to the green light pervading the room, and when therefore the color is due not to contrast alone, but also to the effect of green-fatigue.

All these phenomena admit of an easy physiological explanation, but directly contradict the psychological claim, namely, that the red of the shadow, even when due to contrast alone, persists when the neighboring green field is excluded. Let us, for example, consider the explanation according to Hering's physiological theory. He maintains that the excitation of any portion of the retina induces

a stimulation of the neighboring parts, tending to produce in them the sensation of the complementary color; this being the physiological cause of simultaneous contrast. This would account for the color of the shadow in the original fixation. The continued action of the green on one portion of the retina would produce green-fatigue, by diminishing the green-red visual substance (or by building it up above the normal, according as green is the dissimilative or the assimilative color.) The red process on the other portion of the retina would produce the opposite effect, giving rise to a slight red-fatigue. On suppressing the external color-stimulus, (by closing the shutter or by moving the tube,) each portion of the retina tends to return to its normal condition, with the effect that the green yields to red and the red to green.

Having now learned that the red when it persists cannot be merely a contrast red, but must be an effect of green-fatigue, perhaps we can explain the phenomena which Helmholtz describes, in accordance with the physiological theory. Helmholtz' first experiment, which we quoted above, we make as follows: Let first the shutter be closed, excluding green light, and let the movable tube be so fixed that it is directed upon the subsequent position of the shadow, without including any of the neighboring field. Look now with one eye through the tube, the other being closed. The ground will appear grey. If now, with the eye still at the tube, the shutter be opened, causing the shadow, no change of color will be observed, but merely a slight one of illumination, or perhaps a somewhat greenish tint due to diffused light. This latter will yield to a faint negative (fatigue-induced) red on closing the shutter, lasting for a moment only. The shadow under these circumstances naturally does not appear red; for the physiological cause of the redness is not present, in that there has been no exposure of the retina to the green light of the field.

To one not looking through the tube, however, when the shutter is opened, the shadow at once appears red and the ground a whitish green, which rapidly becomes weakened in intensity. The latter fact is due to the diminished sensitiveness to green rays, on account of retinal fatigue; or, in Hering's language, the exposure of the retina to green light rapidly modifies the green-red visual substance, diminishing the sensitiveness to green and increasing the sensitiveness to red; the stimulus from the green rays remaining constant, the weight of the green element in the total sensation rapidly tends to decrease, of the red element to increase; hence results as total sensation a much lighter green. As the green becomes less intense, the red of the shadow becomes more so, for the same reason.

If now we look again through the tube, first at the shadow with a small portion of the general field at its edge, then at the shadow only, the shadow continues to appear red. For the retina, moving about over the green field, has suffered green-fatigue. Therefore when the green stimuli cease, the tendency is to restore the green-red substance to its normal condition, and the red process results. This condition now persists, even when the shutter is closed, for the color is due not to the objective color of the shadow, nor to the judgment, but to the physiological condition of the retina; and it will persist until equilibrium is restored. That this restoration of equilibrium does gradually take place is a fact overlooked by Helmholtz; but we can easily convince ourselves of it by experiment. After directing the tube onto the shadow alone, with the shutter

open or closed, we observe by patient watching that the red color slowly disappears until finally the field appears white or grey. Von Kries, who supports the psychological explanation, yet acknowledges that the "color does not last indefinitely long, but soon becomes doubtful."[1] The same fact has been observed by several persons who have performed the experiment with me, although they had no suggestion of what would probably occur. This is exactly the result to be expected if we accept the physiological explanation, as we have seen. But from the psychological standpoint it is hard to see why the red color should disappear at all, so long as we continue to look through the tube. For, as Delbœuf says in the passage quoted above, there is no reason to change our decision, if the color is due to an "unconscious anterior judgment," for the observable conditions do not change. We have therefore already strong reasons to doubt the assertion of Helmholtz that the red color is one which persists "after the circumstances which caused it have disappeared," owing to continued "deception of judgment."

The length of time during which the red color persists varies greatly, and sometimes the disappearance is very slow. It seems to bear some relation to the strength of the green light, and the length of time that the eye has been exposed to it. If, while the red still persists, one lay aside the tube and glance at the field, (the shutter being closed or the colored glass removed,) the color at once disappears; for it is thrust "under the threshold" by the stronger sensations coming from the field. But one can often see it again when these stronger sensations cease on applying the eye again to the tube. If one continue however to gaze through the tube alone after obtaining the red color, there are no neighboring active fields to influence it and no rival processes to interfere, and the change is sometimes very slow. A subsequent experiment will illustrate another case where under similar conditions an after-image is long retained, showing that the slowness with which the equilibrium is restored in this experiment is by no means exceptional.

When the sensation of red has become weak, there occurs a doubtful stage, where the phenomena are liable to vary in different observers. For example, while still watching at the tube with the shutter closed, if the other (unfatigued) eye look through a second tube at the white ground, and its field be compared with that of the observing eye, the red of the latter will sometimes seem to disappear suddenly, and the field is seen to be white. Von Kries speaks also of being able, at this stage (where the process has become very weak), to hasten or delay the change, and see the color almost at will red or white. This appears to belong to that class of cases where, the sensation being weak, it is often doubtful whether it exists or not. We often cannot tell whether we hear or imagine a faint sound, and sometimes under favorable circumstances we think that a musical note still continues, even after it has ceased. So here, at this doubtful stage, the sensation may be imagined for a short time after it ceases, and then disappear on comparing it with the white field. This says nothing however against the original red having been due to actual physiological processes. Quite as often, when one thinks the red color entirely gone, it will again be seen if the field seen through the original tube be compared with the grey field through the second tube. Again, after long gazing through the tube, there

[1] Gesichtsempfindungen, p. 132.

is always a darkening of the field underneath, due to fatigue of the black-white substance, and at its edges more or less contrast with the black sides of the tube. This effect is liable sometimes to be taken for a weak sensation of color.

These are all cases belonging to a large class of judgments where very weak nervous processes answering to sensations and nervous processes answering to pure mental images, are indistinguishable from one another, and where weak impressions are easily misinterpreted.[1] But they have not necessarily anything to do with color-contrast and with the cause of the shadows which we are considering.

We have thus reviewed all the "crucial" experiments of Helmholtz, and found them valueless as proofs of the psychological nature of color-contrast. A few further experiments are of interest, and easily admit of a physiological explanation. For instance, if, laying aside the tube, we steadily fixate for a considerable time one point of the middle of the shadow, the red becomes weaker and finally almost disappears, leaving the shadow greyish except at the edges, where the contrast is more marked. This is because the fixation is favorable to the restoration of the equilibrium disturbed by green-fatigue. If again we fixate the shadow, and then after a considerable time shut off the green light, the rest of the retina is subject to a bright red sensation, due to the restoration of the exhausted green-red substance; and the portion corresponding to the shadow experiences the sensation of green, due largely to contrast with the red.

Finally, the following experiment, to which we have already referred, illustrates the slow disappearance of an after-image under favorable circumstances, and thus shows that the same phenomenon in our tube experiment is not exceptional. Admit only white light to the room, then look for a time through the tube at a colored field (e. g., a piece of red paper); then move the tube so as to cover a white or grey ground, or remove the colored paper. The color complementary to the original field (in this case green) will be the color now seen, and not the original color (red), nor white or grey. And this color remains visible for a long period of time, as the red did in the shadow experiment. In the shadow experiment, after gazing at an apparently colored field (the shadow), the same color continues to be seen in the tube on a gray ground; in this experiment the complementary color. But the same law operates in both cases; for the two colored fields observed are due to different causes. In the first, the red is due, not to objective, but to subjective stimuli. The continuance of this red produces no red-exhaustion, but the gradually disappearing green-exhaustion merely continues, and is present so long as the red color continues as its sign. In this second experiment the color is objective, and produces exhaustion of that color, leading to a restoration of equilibrium which produces the sensation of its complementary color.

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[1] On these cases, Prof. Sully, "Illusions," (Internat. Sci. Series), p. 55: "It is a law of sensory stimulation that an impression persists for an appreciable time after the cessation of the action of the stimulus. This 'after-sensation' will clearly lead to illusion, in so far as we tend to think of the stimulus as still at work."—p. 41: "It is evident that all indistinct impressions are liable to be wrongly classed. Sensations answering to a given color or form are, when faint, easily confused with other sensations, and so an opening occurs for illusion."—p. 39: "It is possible for the quality of an impression, as, for example, of a sensation of color, to be appreciably modified when there is a strong tendency to regard it in one particular way."

By the above experiments we have endeavored to prove the invalidity of the claims that colored shadows must necessarily be explained as an effect of deception of judgment, and that they are therefore a proof of the psychological nature of color contrast. We leave it still an open question whether contrast is psychological or physiological in its nature. Hering's formulæ seem to apply to it as well as do those of Helmholtz. Colored shadows throw no light on the controversy; for the experiments with colored shadows, which have been supposed to prove conclusively the psychological theory, are experiments not in color-contrast but in retinal fatigue. The unwarranted claims of the "psychologists" have resulted from the fact that hitherto care has not been taken to distinguish between the two phases of the shadow—that of pure contrast, which ordinarily is never seen, and that due to fatigue by the prevailing light, which begins at once over the entire retina, since the eye keeps moving continually over the field. Helmholtz waited for this effect before performing his tube experiments, as we notice by his direction to allow the blue of the shadow first to become intensely developed; and then he wrongly called the result an effect of contrast. His followers have done the same. Our positive result, besides the separation of the two phases of the shadow, is this: We have seen that the color of the shadow persists in the experiments with the tube only when it is due to retinal fatigue; that its long continuance is paralleled by an experiment in which the persisting color is an after-image which is not caused by "unconscious anterior judgments" induced by the belief that we gaze through colored media; that the color gradually disappears, a fact which cannot be accounted for by the psychological theory; that when it disappears suddenly by comparison with the grey field outside, it is because the sensation is thrust under the threshold, or has reached the stage where it is more imagined than seen; and that all the other phenomena observed are entirely compatible with a physiological explanation—some of them being thus even better accounted for. These facts, we believe, entirely disprove the claim that only a psychological explanation of colored shadows is possible, and make some physiological explanation at least possible—perhaps even absolutely necessary.

EDMUND B. DELABARRE.

Ueber den Grund der Abweichungen von dem Weber'schen Gesetz bei Lichtempfindungen. H. EBBINGHAUS. Archiv f. d. ges. Phys. Bd. XLV.

The researches of König and Brodhun, more rigid than any that have hitherto been made (this JOURNAL, Vol. II, p. 330), as to the degree of exactness with which Weber's Law applies to sensations of light-intensity, over a wide range of variation of intensity, and for six different points of the color scale, have induced Ebbinghaus to endeavor to account for the fact that departure from the law is the rule, and that its exact applicability holds only over a small range of medium intensities. Without attempting any explanation of the fact that the intensity of a sensation increases as the logarithm of the intensity of its objective cause, he endeavors to show why that should *not* be the case at the two ends of the intensity-scale, and in the following way. Assuming that the process which goes on in the retina is of a chemical nature, it is necessary to apply to it the conceptions that are current in modern chemical theory. The chemist has given